The evaluation of the environmental impact of road lighting

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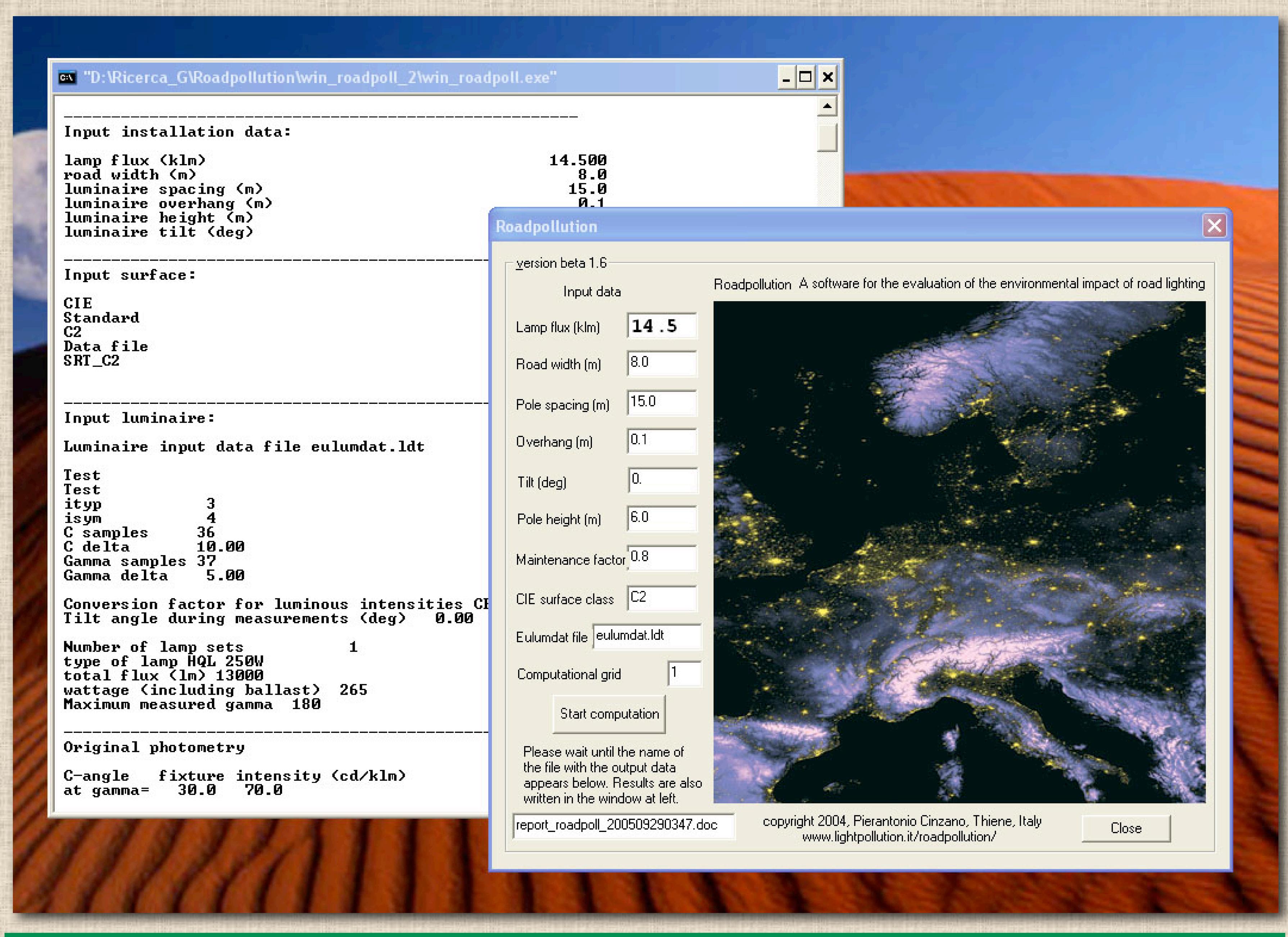
Abstract: Roadpollution is a simple software for the analysis of road lighting installations and for the evaluation of their environmental impact in terms of light pollution produced. It provides a detailed report including a large number of parameters which allow to quantify the quality of the lighting design, its effectiveness in energy saving, its correspondence to the requirements for minimizing light pollution and its compliance to laws against light pollution. This report is an useful "identity card" of the lighting installation where all useful parameters can be found.

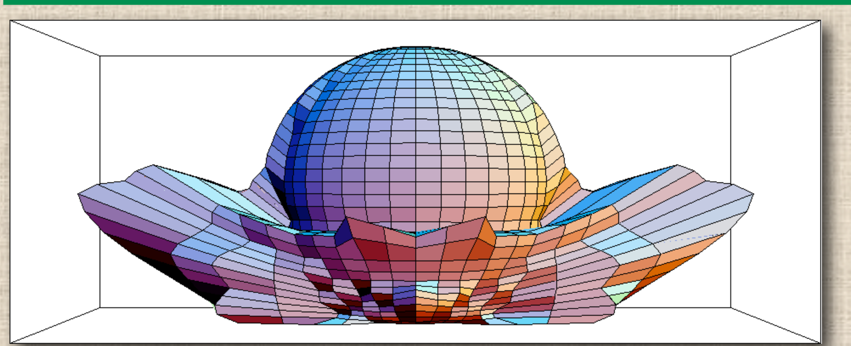
Lighting designers can profitably use Roadpollution to check the quality of their design and to experiment how to improve energy saving and light pollution control. When a satisfying design is reached, the report obtained with Roadpollution can be attached to the lighting plan. It constitutes an additional value and it helps the designer to emphasize the good qualities of the lighting installation toward customers, public opinion and environmentalists. Roadpollution is not intended as a lighting design software, even if it computes all typical parameters: certified softwares and optimization software like Easy Light (www.cielobuio.org) should be used for lighting design.

Roadpollution can be also profitably used by peoples involved in control of light pollution to check the energy saving and the environmental impact of a lighting installation, based on two fundamental documents: the lighting design and the luminaire's photometrical data. In lack of the first, input parameters can be obtained with an on-site inspection of the installation. Note that a check of the compliance of the actual lighting installation with the lighting design should be carried on in any case. The compliance of a lighting installation with laws against light pollution is usually verified directly on the two cited documents, however Roadpollution can help to check the accuracy of the lighting design or when the lighting design is unavailable or incomplete.

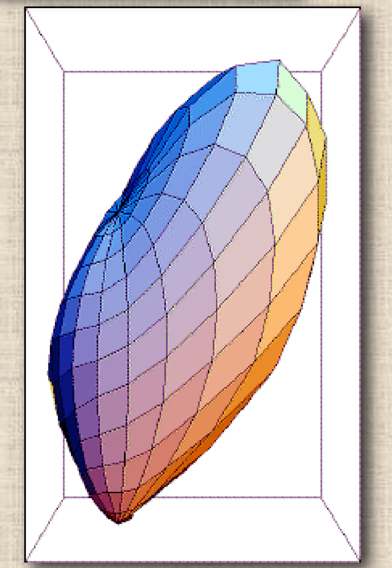


Roadpollution is freely downloadable from www.lightpollution.it/roadpollution/ and it works under Windows XP. It writes a file with a detailed Report in text format with customizable header. Another file contains data tables like e.g. the distributions on the road surface of luminance, horizontal, semicylindrical and vertical illuminance, veiling luminance, glare ratio, etc. In order to obtain correct results users MUST READ the User Manual and FAQs.

The required input data are:
1) Light flux of the adopted lamps. This value can be smaller than the standard output of the lamp when a flux controller is assumed to be active.
2) Road width.
3) Pole spacing.
4) Luminaire overhang in respect to the road border.
5) Luminaire tilt. The tilt should always be zero in lighting installations careful of minimizing light pollution. However the limits to the upward luminous intensity per unit flux required by some laws against light pollution allow small tilts to some luminaires, so this possibility was included in the software. The tilt is intended "in respect to the position of the luminaire in the photometrical data file". This position in rare cases could differ from the "suggested position of installation" or from the zero tilt of their optics.
6) Pole height.
7) Maintenance factor, accounting for lamp depreciation etc.
8) Kind of surface according to CIE classification (C1, C2, R1, R2, R3, R4).
9) Name of the file with the input photometrical data in Eulumdat format of the chosen combination of fixture, optics, lamp and lamp position. The Roadpollution Tools allow users to convert IES 1991 and IES LM-63-95 files of type C photometry in a pseudo-Eulumdat format readable from Roadpollution. The responsible user should verify line by line the compliance with Eulumdat format (see the User Manual) because non-standard files could produce wrong results.
10) Computational grid: 1 for italian standard UNI 10439; 2 for CIE Publ. 140 (2000) and european standard EN 13201-3 (2004); 3 for ANSI-IESNA RP-8-00; 4 for a 100 x 50 high resolution grid; 5 to 9 for grids customized by the user by editing the file grid.dat.



Roadpollution is made for two lane roadways but it can be used for more complex roads by properly specifying the grid size and the observer position. For other lighting installations, it can provide those parameters which do not depend on the luminaire disposition and the lighted area (e.g. upward light intensities and upward fluxes of the luminaires). It also evaluates the upward intensities per unit flux of a projector, its upward fluxes and its illuminance distribution on the ground surface. An unsupported feature allows to obtain a 3D plot of the upward intensity of road lighting installations, including both fixture emission and road reflection (a simple model of Lambertian plus specular reflection fitted to CIE road tables).



What the most interesting parameters in the Roadpollution Report are?

A proper minimization of light pollution requires that (1) the light reflected by lighted surfaces be limited to the necessary by avoiding overlighting, (2) the upward light emission by the luminaires be minimized, (3) the downward light emission wasted by the luminaire outside the road surface be minimized as much as possible so that the light reflected needlessly from these surfaces be minimized too.

One of the first rules for minimizing light pollution and maximizing energy saving is to not over-light. Hence firstly it should be checked that the **average maintained luminance** of the road surface is both *not lower* than the level required by safety rules for that road class and *not higher* than it. A luminance higher than the necessary means that more energy than necessary is consumed and more light pollution than necessary is produced by the light reflected from the road surface. This is always should be explicitly required by a good law against light pollution (e.g. the majority of the regional laws in Italy prescribe it). For some kind of installations, like e.g. pedestrian areas, safety rules refers to the **maintained illuminance** rather than to the luminance, so this one will be the parameter to be checked. Where laws against light pollution prescribe the use of flux controllers to reduce luminance/illuminance after curfew time, they can be also used for small adjustments of the luminance/illuminance before curfew.

In order to check the energy saving capabilities of a lighting installation, fundamental quantities are the **installed lamp flux per unit length per unit luminance** and the **installed lamp flux per unit area per unit luminance** (also called **photometric efficacy**). The first is useful for comparing more installations on the same road and the second is better for comparing installations on roads of different width. These quantities should be as small as possible. Good installations with full-cut-off fixtures are expected to arrive under 300 klm/km per cd/m^2 and 40 lm/cd, with best reported values down to 200 klm/km per cd/m^2 and 25-30 lm/cd respectively.

If the photometric efficacy is too large, a fundamental parameter to recognize the causes is the **utilance** or **used fraction of the luminaire flux**, which gives direct information on the quantity of light that the lighting design makes to be sent on the road surface and outside of it. The reduction of the light wasted outside the road, i.e. the maximization of the utilance, not only is the more effective way to reduce energy consumption but also allows to reduce the useless light pollution produced by the light reflected by those surfaces which should not be lighted. The **fixture efficiency** (fraction of lamp light which is actually emitted) is a less important parameter because a fixture could be poorly efficient but it could be able to send a greater fraction of light on the road surface whereas a more efficient fixture could waste a lot of light outside the road. However, a look to the calculated **downward light output ratio DLOR** (downward fixture efficiency) it is worth. It is unlikely that a fixture with downward efficiency under the common range 65%-80% will allow a lighting design with a good photometric efficacy. The **utilization factor** (utilance times the fixture efficiency, expressed as fraction) is another useful parameter but it mixes the utilance which depends on the lighting installation design with the fixture efficiency which depends on the fixture choice. It is preferable to analyze them separately.

The **lamp efficacy** gives another important information related to the energy saving. It should be the larger available for the lamp class required by the kind of lighting.

The product of the photometric efficacy times the lamp efficacy gives the **power per unit length per unit luminance** or the **power per unit area per unit luminance** (sometimes called **power efficacy** or **energetic efficacy**). Even if these could seems more meaningful parameters, usually it is more useful to evaluate separately the photometric efficacy and the lamp efficacy because the first strictly depends on the lighting design whereas the second depends on the lamp choice. The lighting designer should obtain the best for each of them. The power efficacy could become important in some comparisons like e.g. if we have to compare an installation with low poles, large spread fixtures and low power lamps with another with high poles, narrow spread fixtures and higher power lamps. In this case the photometric efficacy is not sufficient for a correct comparison because the lamp efficacy changes with the power of the lamp.

A parameter not related to the energy expense but to the expenses for installation and maintenance is the **number of luminaire per unit road length** (luminaires per km). It is less important than the photometric efficacy because usually a larger energy saving should be preferred to a smaller number of luminaires. In facts a larger energy saving usually pays off a larger installation expense in a fraction of the lifetime.

A look to the **threshold increment TI** and to the **glare rating GR** give informations on the care that the lighting designer devoted to the control of the disturb produced by the glare.

The light pollution produced by artificial light emitted upward from the fixtures of a light installation depends on the direction of emission of the light. Emissions at lower gamma, nearest to the horizon plane, are particularly effective in producing the adverse effects of light pollution because propagate more and add efficiently. Integrated parameters like the "upward light flux" (UFR) are then poorly useful. A good way to investigate the light pollution by direct upward emission from the fixtures of a lighting installation is to look at the table of the **Upward intensity per unit luminaire flux** (cd/klm). It gives for a sample of directions, defined by elevation alpha and azimuth omega, the upward intensity of the luminaire emission per unit flux emitted by the luminaire. For comparison the emission of the road surface calculated assuming dark asphalt reflectivity is also shown, together with the ratio between the first and the second. We could consider "minimized" the unnecessary upward emission by luminaires when it is smaller than 10% of the road emission (assuming that the road is not over-lighted). Hence the ratio should be less than 0.1 in particular at low elevations over the horizon.

The **maximum upward luminaire intensity per unit luminaire flux** allows checking if the installation is compliant with the limits required by some laws against light pollution. Some laws adopt a limit of 0.49 cd/klm at gamma larger than 90 degrees for almost any kind of installation with few exceptions. Users should verify if the limit to comply with is an *intensity per unit luminaire flux* or an *intensity per unit lamp flux*. The first quantity is the second divided by the fixture efficiency (LORL, light output ratio of the luminaire) and is the one which make sense in limiting light pollution. When the fixture is tilted, Roadpollution provides the intensities of the inclined luminaire interpolated on the grid of angles C, gamma. It allows to recognize rapidly if in some directions the limit is surpassed. If the interpolation uncertainty cannot be neglected, the photometry is not interpolated but the new angles C, gamma after inclination are computed.

Finally, even if integrated quantities are usually not effective to evaluate light pollution, two of them are more appropriate than the obsolete upward light flux ratio (UFR). The *upward scattered flux factor* and the *low-angle upward scattered flux factor* give the fraction of luminaire flux, in percent, which is emitted upward and is scattered by molecules and aerosols along its path in a standard clean atmosphere. The first factor is computed on the entire upper hemisphere and the second, much more interesting, at low angles over the horizon (in the range of gamma 90-120 degrees) where light pollution is particularly propagative and additive. It is interesting compare these factors for (a) the direct emission by fixtures (pollution to be minimized) and (b) the reflection by surfaces lighted from wasted light (pollution to be minimized) with the factors for (c) the road surface (the only truly necessary pollution). The **increase of scattered flux due to direct emission** and the **increase of scatter flux due to out-of-road light reflection** over the scattered flux due to reflection from the road surface should be always under 10%, both in the **hemispheric** and in the **low-angle** case. It should be recognized, however, that the light wasted on the surfaces surrounding the road, and the consequent light reflection, is very difficult to control so much. This is the reason because, so far, laws against light pollution do not limit it quantitatively.

www.lightpollution.it/roadpollution

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